The World Meteorological Organization's Fourth International Workshop on Tropical Cyclone Landfall Processes (IWTCLP-IV): A Summary

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Tropical Cyclone Research Review

Abstract

The Fourth International Workshop on Tropical Cyclone Landfall Processes (IWTCLP-4) was held in Macau, China from 5-7 December 2017. The workshop was organized by World Meteorological Organization's (WMO's) Expert Team on Tropical Cyclone Landfall Processes in partnership with WMO's Tropical Cyclone Program. The workshop provided a forum for discussion between researchers and forecasters on the current status of tropical cyclone landfall processes and on priorities and opportunities for research. More than 60 leading research scientists and warning specialists working on topics related to tropical cyclone landfall examined current knowledge, forecasting and research trends from an integrated global perspective. The workshop offered a number of recommendations for future forecasting studies and research with special regard to the varying needs of different tropical cyclone affected regions. The recommendations emanating from the workshop will be presented at the upcoming Ninth International Workshop on Tropical Cyclones (IWTC-9) (Hawaii, USA, 3-7 December 2018).

1. Introduction

The Fourth International Workshop on Tropical Cyclone Landfall Processes (IWTCLP-IV), sponsored by the World Meteorological Organization (WMO), was recently held in Macau, China from December 5-7, 2017. The IWTCLP series of workshops augments the traditional, quadrennial WMO-sponsored International Workshop on Tropical Cyclones (IWTC). Both the IWTC and the IWTCLP are organized under the auspices of the WMO Working Group on Tropical Meteorology Research (WGTMR), which is a part of the WMO World Weather Research Program (WWRP), and in partnership with the WMO Tropical Cyclone (TC) Panel. First started in 1986, these workshops bring together forecasters and researchers from countries around the world (Figure 1) that are impacted by TCs to discuss the latest research and forecast

advances for TCs and share best practices to improve TC forecasts globally. The workshops have continued as a regular feature of WMO efforts to encourage the advancement of TC forecasting and improve ways of communicating TC hazards to the general public.

As its name suggests, the focus of the IWTCLP is on processes that impact communities when TCs make landfall. Specifically, the objectives of the IWTCLP are:

- To describe tropical cyclone landfall impacts and the required meteorological variables that must be observed, analyzed, and predicted;
- To describe present forecast capabilities for these meteorological variables and to establish the gaps or deficiencies in a prioritized list of forecast variables;
- To describe national or international research programs that the WGTMR Tropical Cyclone Panel may be affiliated with that will address these forecast deficiencies; and
- To improve understanding of the behavior of landfalling tropical cyclones.

The first IWTCLP was held in Macao, China in 2005 (Table 1). Subsequent workshops were held in 2009 in Shanghai, and in 2014 in Jeju, Republic of Korea (coincident with the IWTC-VIII). Online documentation, including working documents, reports, and presentations for the IWTCLP-IV, as well as previous workshops such as IWTC-VII and IWTC-VIII/IWTCLP-III, can be found at the WMO site, http://www.wmo.int/pages/prog/www/tcp/Activities.html. Several books, manuscripts, and compendia have also been published that summarize and describe past meetings. These include the books entitled "A Global View of Tropical Cyclones" (Elsberry et al. 1987) and "Global Perspectives on Tropical Cyclones: From Science to Mitigation" (Chan and Kepert 2010), and an article summarizing research on TC rainfall from previous IWTCLP meetings (Chen et al. 2010).

The purpose of this article is to provide a summary of the activities of the IWTCLP-IV. This includes a discussion of the theme of the workshop, an overview of the program, a brief summary of the material presented, and a presentation of the primary outcome of the workshop; i.e., a set of recommendations submitted to the WMO that is directed at the TC operational community, TC research community, the integrated TC operational and research community, and the WMO itself. Additional information on the workshop is provided in companion papers to this manuscript.

2. IWTCLP-IV Summary

The theme of the IWTCLP-IV was "TC Landfall Impacts: Transitioning from Observations and Modeling to Greater Understanding and Better Forecasts". This theme was developed in acknowledgement of the basic necessity to conduct research to improve the development and communication of forecasts for landfalling TCs. Several recent high-impact landfalling TCs, such as Typhoons Hato (2017) and Damrey (2017) in the western North Pacific; Hurricanes Harvey (2017), Irma (2017), and Maria (2017) in the Atlantic; and Cyclone Debbie (2017) in the East Australian Region, highlight this need for improved forecasts and improved communication of these forecasts. At the same time, there are several ongoing observational and modeling field campaigns designed to study TCs at and after landfall. One of the goals of the workshop was to provide a forum for the principal investigators of these projects to present observations, model validations, and research results from the projects to the broader operational and research community and explore possible pathways for transitioning from this research to forecast improvements.

The International Organizing Committee (IOC) consisted of members of the WMO Expert Team on Landfall Processes (ETLP) plus additional forecasters and researchers from around the world (Table 2). The program consisted of four focus areas targeting the primary impacts of TCs at landfall and the communication of these impacts: 1) Rapid changes in track, intensity, and structure at landfall; 2) Storm surge; 3) Rainfall; and 4) Effective communications and warnings. Table 3 provides a complete list of all oral presentations given at the IWTCLP-IV. Each of these focus areas had an associated focus area lead, who was responsible for assembling a working group to assist with writing a report on the research advances in the given focus area since the last IWTCLP (in 2014). Additional material was provided by representatives from forecasting agencies on the challenges related to each focus area. Each focus area lead gave a keynote presentation summarizing the research advances and forecast challenges to begin the corresponding focus area session. All presentations can be accessed online at http://www.wmo.int/pages/prog/arep/wwrp/new/IWTCLP4-ppt.html. Furthermore, these focus area reports have now been converted to companion articles in this special issue of TCRR in order to provide a wide distribution.

Additionally, four contributed talks from researchers were given in each focus area to highlight research studies in progress that are expected to contribute new understanding and lead to improved forecasts of TCs at landfall (see Table 3). An example of these talks in the track, intensity, and structure focus area was the presentation by Elsberry and Tsai of a research study that will extend to 7 days the lead time for western North Pacific TC intensity forecasts at landfall. This greater lead time is important as the concentration of people and industry has increased in coastal regions, and thus more time is needed for disaster prevention activities. This Weighted Analog Intensity Prediction technique only requires a track forecast that indicates the

time of a landfall and the initial intensity, and it is calculated in a few minutes on a desktop computer, so all TC warning centers could use such a technique. Feng, Duan, and Yu presented a data assimilation research study that used Doppler radar observations along the China coast during three typhoon landfalls. They tested radar observations when the typhoon was within 100 km, between 100 km and 200 km, and at distances greater than 200 km, and concluded that radar data when the TC was within 100 km was optimum for improving both the intensity and track forecasts at landfall. Kao and Jou also used Doppler radar observations to examine the inner core structure of TY Haitang (2005) as it made landfall along the high terrain of Taiwan. As described in the Leroux et al. (2018) summary article in this special issue, interaction of the typhoon circulation with steep topography is being widely studied to improve understanding and improve TC landfall forecasts. Kao and Jou demonstrated that a coastal low-level jet along the terrain played a key role in that interaction, and that vertical wind shear differences may be related to whether the typhoon has a looping track upstream of the terrain, which is a difficult forecast situation.

In the storm surge focus area, U. C. Mohanty indicated that 75% of the TC-related damage in India is due to storm surge, and storm surge is especially dangerous in the Bay of Bengal where the low-lying coastal regions are heavily populated. Four TCs occurred in the Bay of Bengal from October 2013 to December 2016, and even storm surges of 1 m to 2.5 m led to causalties. Such surges on the right side of the track may be related to inertial processes. M.-D. Leroux described storm surge predictions in the Southwest Indian Ocean with a focus on the island of La Reunion. Leroux described an ensemble approach to specify the surge uncertainty using a database of 8,640 hypothetical storms. These storm tracks were distributed among a cluster of 40 climatological track categories. Depending on which of these 40 climatological

track categories best matches the target storm track forecast near La Reunion, the likely surge heights and the surge uncertainty can be specified.

In the rainfall focus area, W.-C. Woo described a satellite reflectivity retrieval technique for the TC Quantitative Precipitation Estimation at the Hong Kong Observatory that takes advantage of the Himawari-8 high temporal and spatial resolution. This multi-layer perception artificial neural network has a training algorithm with backward propagation in which the performance is optimized through repeated cycles with or without the visible channel on the Himawari-8, and even hours are used for training and odd hours for verification. When the synthetic reflectivities were blended with the real reflectivities, the daytime verifications had a probability of detection >70% for reflectivity values of 24 dBZ. Zifeng Yu described a research study of the intensities and rainfall distributions for 133 TC landfalls over China. Stronger typhoons (Categories 4 and 5) had higher azimuthal-mean rain rates. The asymmetric wavenumber one rain was generally downshear and downshear-left except for some weaker typhoons.

In the communications and effective warnings focus area, Armstrong Cheng described the WMO Global Multi-hazard Alert System (GMAS) as an approach for effective delivery of warnings, as well as being the authoritative warnings and information source to the United Nations agencies and the humanitarian community. Some of the benefits of the GMAS are standardization in a common alerting protocol, sharing, harmonization, capacity development, and providing decision-makers with free access to an authoritative source. A focus is on impacts forecasting by giving the likelihood of the event in Very Low to High categories with an impact scale indicated by green, yellow, or red colors. The Multi-hazard Early Warning System in the Philippines provided by PAGASA was described by Cecilia Monteverde. This is also a color-

coded warning system for heavy rain and floods, TCs, gale-force winds, and storm surges. Communication and dissemination of these warnings is by various modes including mobile phone apps, social websites, and electronic signs along major highways with the objective of providing specific information as to what the public should do to ensure their safety. Finally, Wai-Ken Wong of the Hong Kong Observatory shared some forecaster issues in communication and effective warnings. Wong emphasized the need for active analysis of social media messages, and especially the need to counter rumors by issuing Weather Notes. New tools for the forecasters include Big Data Analytics and crowd sourcing, and provision of track probability graphics based on products from multiple centers. Wong also emphasized the need for forecasters to establish collaborations, and partnerships to communicate warnings that are effective in terms of improving community response to the hazard.

There was also a poster session for researchers and forecasters to present their latest work on TC landfall processes. A total of 35 posters were accepted for presentation. These posters included such topics as a predictability study of tropical cyclones over the Bay of Bengal using high resolution mesoscale models, a case study of orographic convection and mountain waves in a landfalling typhoon, and the characteristics of unusual TC tracks near Taiwan Island and their forecast uncertainty.

In addition to the discussions related to the focus areas described above, there was a special session related to recent high-impact landfalling TCs. Much discussion occurred on Typhoon Hato, which had severely impacted Macau just three months prior to the workshop. Hato underwent rapid intensification in the hours prior to landfall in Macau and resulted in several deaths during landfall. Forecasters were delayed in elevating the threat level associated with this typhoon. Talks associated with Hato focused on all three hazards associated with the

storm (rapid intensification, storm surge, and rainfall). Another talk discussed the challenges and the performance of the Cuban forecasting agency in communicating the risk associated with Hurricane Irma as it made landfall in Cuba.

Another special session focused on the field campaigns and model development projects ongoing and sanctioned by the WMO. These include

- Experiment of Typhoon Intensity Changes in the Coastal Area (EXOTICCA; http://www.typhooncommittee.org/exoticca/),
- Typhoon Landfall Forecast Development Project (TLFDP; https://www.wmo.int/pages/prog/arep/wwrp/new/TLFDP.html),
- Understanding and Predicting Rainfall in Landfalling Tropical Cyclones (UPDRAFT; https://www.wmo.int/pages/prog/arep/wwrp/new/UPDRAFT_rdp.html),
- Sensing Hazards using Operational Unmanned Technology (SHOUT;https://uas.noaa.gov/SHOUT),
- EPOCH (East Pacific Origins and Characteristics of Hurricanes; https://atmospheres.gsfc.nasa.gov/meso/index.php?section=260).

EXOTICCA, led by scientists at the Shanghai Typhoon Institute, focuses on intensity and structure changes prior to landfall by collecting observations, including airborne data from an aircraft operated by Hong Kong Observatory and rocket-based dropsonde measurements launched from Hainan Island, in TCs prior to landfall. TLFDP, also led by Shanghai Typhoon Institute, focuses on developing, optimizing, and verifying techniques for predicting TC track and intensity using numerical models. UPDRAFT, led by scientists at Nanjing University, focuses on rainfall from TCs after landfall by collecting observations from a variety of ground-

based platforms, including rain gauges, polarimetric radars, profilers, and surface stations. SHOUT and EPOCH were two experiments led by NOAA and NASA, respectively, that examined TCs in the Atlantic and East Pacific basins using the NASA Global Hawk aircraft. Part of the work of these two experiments was to test the impact of dropsonde observations from the Global Hawk on TC track, intensity, and structure forecasts.

As the name indicates, EXOTICCA is focused on the intensity changes of typhoons as they make landfall in China from either the South China Sea (SCS) or East China Sea (ECS). A key objective is to develop and deploy new instruments to better observe the intensity changes during landfall. Beginning with a mobile monitoring system update and installing an array of ocean buoys during 2014, a radar wind profiler has been deployed. Collaboration with Hong Kong has provided aircraft-deployed dropwindsondes over the coastal ocean region. An unmanned aircraft deployment unfortunately lasted only 40 minutes. A rocket sounding system had a successful launch in 2017 that reached an altitude of 10 km. An automated radiosonde system was deployed on an offshore island in 2017. An airship for deploying dropsondes from elevations of 18-20 km for up to a month is being developed. Thus far, six ECS and four SCS storms have been observed.

The TLFDP was originally proposed in 2009 at the second IWTCLP. This demonstration project has collected TC forecasts from various warning centers and verified their forecast performance in real-time and in post-season analyses. Strike probability plots have been developed and single-model and multi-model ensemble products have been generated. The proposed TLFDP-IV would be extended to the Atlantic, and to the Indian Ocean in collaboration with the India Meteorological Department. New items would include an expanded Dvorak intensity estimate based on artificial intelligence applied via Big Data ideas. A new variable

would be vortex structure in terms of eyewall radii and other size variables. Impact forecasting will be promoted by use of damage statistics and risk analysis.

The UPDRAFT progress report for 2016-2017 includes data assimilation of various observations in landfalling TCs, and a 3DVAR hybrid ensemble with a dynamical constraint on the gradient wind balance. A Central Regional Reanalysis of typhoons during 2003-2014 has been carried out with a horizontal resolution of 19 km, 45 sigma levels in the vertical to 10 hPa, and outputs every 6 h. Simulations with a vertical grid interval of 37 m of roll vortices in the planetary boundary layer have been compared with in situ observations. An UPDRAFT field campaign measured dropsize distributions with a videosonde, radar, and a disdrometer during four landfalling TCs on the China coast. The majority of the raindrops were less than 3 mm in diameter, and with a high concentration of smaller raindrops. In one case, 1-2 mm diameter drops contributed to 53% of the rainfall when the rain rate was > 25 mm/h.

The NASA Global Hawk observations continued under the sponsorship of NOAA in 2016 with missions in Hurricanes Gaston, Hermine, Karl, and Matthew in the Atlantic. During 2017, Global Hawk observations were again collected in the EPOCH field experiment, with perhaps the most interesting Global Hawk observations being in Hurricane Harvey that later produced record rainfall in the Houston Texas area. Improved track forecasts, intensity forecasts, and storm size forecasts were documented in presentation at the 2017 U.S. Interdepartmental Hurricane Conference.

3. IWTCLP-IV Recommendations for the WMO

The final portion of the workshop consisted of a set of breakout sessions where various questions were considered that tied together the issues and challenges raised in the focus area

presentations, high-impact TC discussions, and observational and model research project presentations, with the intent of identifying recommendations that would be made to the WMO on behalf of the IWTCLP-IV. These recommendations are a significant outcome for the IWTC series of workshops, as they mark a set of concrete benchmarks which can be used to identify progress made in between two workshops. The recommendations that arose from IWTCLP-IV touch on all aspects of the four focus areas; i.e., rapid changes in track, intensity, and structure at landfall; storm surge; rainfall; and effective warnings and communication. They are directed at various communities – the operational forecasting community, the research community, the integrated operational and research communities, and the WMO itself. These recommendations are presented below.

In recognition of the theme ``Transitioning from Observations and Modeling to Greater Understanding and Better Forecasts", the IWTCLP-4 recommends that:

1) *Operational community*

- The TC operational community develop impact-based products that include a specification of uncertainty on forecasts of track, intensity, and structure changes; rainfall; and storm surge using, e.g., probabilistic or ensemble approaches;
- The TC operational community investigate the benefits of probabilistic storm surge forecasting;
- National TC warning centers provide intensity forecast uncertainty guidance in addition to the current track forecast uncertainty guidance;
- The TC operational community explore the possibility of replacing parametric wind models with wind fields dynamically predicted from numerical models to more accurately depict wind structure for improved storm surge forecasts;

- The TC operational community consider integrating related effects (such as wave, river flow, and precipitation) in evaluating storm surge, defined as anomaly from tide level, and further shifting expressions toward coastal inundation information when communicating the risk to the public;
- The TC operational community explore nowcasting models of TC rainfall based on all available observations including in-situ, satellite, and radar that depict real-time precipitation structure, including the eyewall and rainbands;
- The TC operational community communicate warning and verification messages in graphics, animations, and photos to build engagement and provide further evidence of the risk, e.g., of the current weather or of the weather during similar past events that affected the same area;
- The TC operational community work with social and behavioral scientists, social media specialists, and commercial communicators to optimize effective communication of hazards, warnings, and past impacts;
- The TC operational community cultivate partnerships with key opinion leaders in the community and empower them with the information and education necessary for them to positively impact others;

2) Research community

- The TC research community seek opportunities to organize dedicated field campaigns in all basins and increase in situ data and/or leverage existing data from previous field campaigns to investigate TC behavior, particularly those near land;
- The TC research community investigate means of mitigating loss of microwave data using other satellite platforms and aircraft data;

- The TC research community explore ways of fully exploiting capabilities of recently-launched satellite platforms such as Himawari, FY, GOES-16, CYGNSS;
- The TC research community further explore the causes of track deflections including, e.g., impacts of orography and synoptic-scale forcing;
- The TC research community continue to explore physical mechanisms underlying track, structure, and intensity changes prior to landfall as well as rainfall amounts and distributions using existing and planned observational field campaigns and numerical model output;
- The TC research community develop tools to extend the lead time for TC intensity guidance and refine intensity spread guidance tools using, e.g., mesoscale model ensemble forecasts;
- The TC research community seek opportunities to (i) provide and share detailed datasets on bathymetry (ideally high resolution and frequently updated) and a storm surge data dossier including post-event field survey results and (ii) to install tide gauges in coastal areas and on continental shelves for storm surge monitoring and forecast improvements;
- The TC research community develop coupled (e.g. wave, tide, river, flood etc.) numerical models to estimate total sea level, which will lead to water level over land;
- The TC research community further test high-resolution TC rainfall numerical models, including cloud-resolving models, and develop improved verification methods for rainfall forecasts in order to understand model weaknesses, including weaknesses associated with microphysical processes;

- The TC research community document cases with strong TC-environment interactions (including remote rainfall) and develop conceptual models of these cases;
- The TC research community develop new techniques for TC analysis and forecasting by using bigdata and artificial intelligence;

3) Integrated operational and research community

- The TC research and operational communities develop and implement the ability to assimilate all observations in the TC inner core (e.g., within 100 km) and near environment when the TC is near landfall, including, but not limited to, coastal Doppler radar velocity, coastal HF radar, airborne flight-level and dropsonde data, surface and upper-air observations, buoy data, and satellite-derived winds, sea-surface temperature, and sea-surface height anomalies;
- The TC operational community develop and implement testbeds and share verification to regularly interact with the research community on the latest research results on rapid changes in track, structure, and intensity prior to landfall, as well as predecessor rainfall and that during landfall, particularly for challenging, high-impact cases;
- The TC research and operational communities use Forecast Demonstration Projects (FDPs), Research Development Projects (RDPs), Observing System Experiments (OSEs), and Observing System Simulation Experiments (OSSEs) to test the impact of existing, new, and/or upgraded observations, formats, and strategies on operational numerical model forecasts of TC intensity, track, structure, rainfall, and storm surge, not only on target TCs but on TCs in downstream basins of the world;

4) WMO

- WMO send letters of commendation to recent and current observational and forecasting-based research programs and encourage attempts to continue these programs or generate new ones;
- WMO send letters of commendation to the satellite agencies of programs that have launched and currently maintain satellite products of significant value for global TC operational forecasting and research, including recent geostationary satellites Himawari, FY, and GOES-16, the full suite of microwave imagery, and new satellite constellations such as CYGNSS.

These recommendations are intended as actionable items from the targeted communities. They will be presented at the next IWTC, to be held 3-7 December 2018 in Honolulu, USA.

4. Summary

The IWTCLP-IV successfully brought together forecasters and researchers to engage in fruitful discussions of the capabilities, deficiencies, and opportunities of producing and effectively communicating forecasts of TC hazards at landfall. These discussions focused on the main landfall hazards of rapid changes in track, intensity, and structure at landfall; storm surge; rainfall; and the effective communication of these hazards. Additional special sessions on notable recent landfalling TCs and research and forecasting observational and modeling projects were also held. Finally, breakout sessions resulted in the creation of 25 recommendations for the TC operational, research, integrated operational and research communities, and the WMO. These recommendations serve as the basis for identifying actions to be taken by the targeted communities prior to the next IWCLP workshop, likely to be held in the next 3-4 years.

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Table 1. Dates and locations of past WMO-sponsored IWTC and IWTCLP meetings.

Workshop	**Dates**	**Location**
IWTC-I	25 November–5 December 1986	Bangkok, Thailand
IWTC-II	27 November-8 December 1989	Manila, Philippines
IWTC-III	22 November-1 December 1993	Huatulco, Mexico
IWTC-IV	21-30 April 1998	Haikou, China
IWTC-V	3-12 December 2002	Cairns, Australia
IWTC-VI	21-30 November 2006	San Jose, Costa Rica
IWTC-VII	15-20 November 2010	La Reunion, France
IWTC-VIII	2-7 December 2014	Jeju, Republic of Korea
IWTCLP-I	21-25 March 2005	Macao, China
IWTCLP-II	19-23 October 2009	Shanghai, China
IWTCLP-III	8-10 December 2014	Jeju, Republic of Korea
IWTCLP-IV	5-7 December 2017	Macao, China

Table 2. International Organizing Committee for the IWTCLP-IV. Focus area leads and membership in WMO Expert Team on Landfall Processes (ETLP) also noted.

Name	Affiliation	Country
Robert Rogers • Chair of IWTCLP-IV • Chair of ETLP • IWTCLP-IV IOC member	NOAA/AOML Hurricane Research Division	USA
Esperanza Cayanan • IWTCLP-IV IOC member	Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)	Philippines
ST Chan • IWTCLP-IV IOC member	Hong Kong Observatory	China
Kevin Cheung • Focus area lead for Rainfall • ETLP member • IWTCLP-IV IOC member	Macquarie University	Australia
Nadao Kohno • Focus area lead for Storm Surge • ETLP member • IWTCLP-IV IOC member	Japan Meteorological Agency	Japan
Xiaotu Lei • ETLP member • IWTCLP-IV IOC member	Shanghai Typhoon Institute	China
Marie-Dominique Leroux • Focus area lead for Rapid Changes in Track, Intensity, and Structure • ETLP member • IWTCLP-IV IOC member	Meteo-France	France
Uma Charan Mohanty • ETLP member • IWTCLP-IV IOC member	Indian Institute of Technology/ Bhubanasewar	India
M Mohapatra • IWTCLP-IV IOC member	Indian Meteorological Department	India
Peter Otto • Focus area lead for Effective Warning and Communication • IWTCLP-IV IOC member	Bureau of Meteorology	Australia

Table 3. List of all oral presentations given at IWTCLP-IV.

FOCUS AREA: Rapid Changes in Track, Intensity, and Structure at Landfall	
Session Lead (Topic Summary)	Marie-Dominique LEROUX
Forecaster Challenges	Esperanza CAYANAN
Extending the Lead Time and Improving the Accuracy of Intensity Forecasts for Tropical Cyclone Landfall in the Western North Pacific	Russell L. ELSBERRY
Understanding Biases in Tropical Cyclone Intensity Forecast Error	John L. McBRIDE
Improved Simulation of Landfall Typhoon Based on Coastal Radar Data Assimilation	Jianing FENG
Inner Core Structure of Landfall Tropical Cyclones with High Terrain	Jong-Dao (Ben) JOU
FOCUS AREA: Storm Surge	
Session Lead (Topic Summary)	Nadao KOHNO
Forecaster Challenges	Shishir DUBE
Prediction of Storm Surge Associated with Land-falling Tropical Cyclones over Bay of Bengal with one-way Coupled Atmosphere-Surge Model	UC MOHANTY
Probabilistic Forecasts of TC-Induced Hazards	Marie-Dominique LEROUX
Coupled Ensemble Tropical Cyclone and Storm Surge Forecasting	Jeff STEWARD
The After-runner Storm Surge along the North Coast of Vietnam	Nguyen BA THUY
FOCUS AREA: Rainfall	
Session Lead (Topic Summary)	Kevin CHEUNG
Forecaster Challenges	M MOHAPATRA
Development of Satellite Refelctivity Retrieval Technique for Tropical Cyclone Rainfall Nowcasting	WC WOO
A New Technique for Landfalling Tropical Cyclone Quantitative Precipitation	Fumin REN
On the Relationship between Intensity and Rainfall Distribution in Tropical Cyclones making Landfall over China	Zifeng YU

Table 3. List of all oral presentations given at IWTCLP-IV.

Evaluation of Global Ensemble Forecast System for Heavy Rain Associated with Land-falling Tropical Cyclones over Indian Coast	Medha DESHPANDE
FOCUS AREA: Communication and Effective Warnings	
Session Lead (Topic Summary)	Peter OTTO
Forecaster Challenges	WK WONG and Peter OTTO
Multi-Hazard Early Warning System (MHEWS) of PAGASA	Maria Cecilia MONTEVERDE
Some Issues	Peter OTTO
Two-way Social Media Use	Peter OTTO
WMO Global Multi-Hazard Alert System (GMAS)	YC (Armstrong) CHENG
SPECIAL SESSION: Recent High-Impact Landfalling Tropical Cyclones from Around the Globe	
Storm Surge Risk in Hong Kong, China associated with Super Typhoon HATO (2017)	DS LAU
Sudden Intensification of Super Typhoon HATO (2017) before landfall on Macau	Iam Fei PUN
Severe Impacts of Hurricane IRMA in Cuba: Forecast Models, Forecast and Warning Processes	Jose RUBIERA
SPECIAL SESSION: Field Campaigns, Research Development Projects, and Forecast Demonstration Project discussions	
Experiment on Typhoon Intensity Change in Coastal Area (EXOTICCA)	Xiaotu LEI
WMO Typhoon Landfall Forecast Demonstration Project (WMO-TLFDP)	Xiaotu LEI
Understanding and PreDiction of Rainfall Associated with landFalling Tropical cyclones (UPDRAFT)	Yuan WANG
Drop Size Distribution Characteristics of Typhoon in Continental China	Kun ZHAO
Emerging Airborne Technologies for improved TC Track and Intensity Forecasting: Preliminary Observations from SHOUT and EPOCH	Peter BLACK

Figure 1. Photo of participants in IWTCLP-IV.